Traumatic Distal Anterior Cerebral Artery Aneurysms – Pathomechanism and Revascularisation Strategies

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Abstract: Traumatic intracranial aneurysms (TICA) of the distal anterior cerebral artery (dACA) are exceptionally rare and display therapeutic challenges due to their angioanatomical characteristics. The objective of this work was to discuss the mechanisms of TICA formation of the dACA and to elucidate the best treatment and revascularization strategies in these patients based on two illustrative cases. Case 1: 20-year-old patient with a traumatic, partially thrombosed 14 × 10 mm aneurysm of the right pericallosal artery (rPericA), distal to the origin of the right callosomarginal artery (rCMA). Complete trapping of the right dissection A3 aneurysm and flow replacement extra-to-intracranial (EC-IC) bypass (STA - radial artery - A4) was performed. Case 2: 16-year-old patient with a traumatic polylobulated, partially thrombosed 16 × 10 mm aneurysm of the rPericA. Microsurgical excision of the A3- segment harboring the aneurysm and flow replacement intra-to-intracranial (IC-IC) bypass via reimplantation of the right remaining PericA on the contralateral PericA (end-to-side anastomosis) was performed (in situ bypass). TICA of the dACA are exceptionally rare. Mechanical vessel wall injury and aneurysm formation of the dACA in blunt head trauma is very likely due to the proximity of the dACA with the rigid free edge of the falx. Given their nature as dissecting (complex) aneurysm, trapping and revascularization is a very important strategy. The interhemispheric cistern offers multiple revascularization options with its numerous donor vessels. The IC-IC bypass is often the simplest revascularization construct.

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Traumatic Distal Anterior Cerebral Artery Aneurysms – Pathomechanism and Revascularisation Strategies

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Traumatic intracranial aneurysms (TICA) of the distal anterior cerebral artery (dACA) are exceptionally rare and display therapeutic challenges due to their angioanatomical characteristics. The objective of this work was to discuss the mechanisms of TICA formation of the dACA and to elucidate the best treatment and revascularization strategies in these patients based on two illustrative cases. *Case 1:* 20-year-old patient with a traumatic, partially thrombosed 14 × 10 mm aneurysm of the right pericallosal artery (rPericA), distal to the origin of the right callosomarginal artery (rCMA). Complete trapping of the right dissection A3 aneurysm and flow replacement extra-to-intracranial (EC-IC) bypass (STA – radial artery – A4) was performed. *Case 2:* 16-year-old patient with a traumatic polylobulated, partially thrombosed 16 × 10 mm aneurysm of the rPericA. Microsurgical excision of the A3- segment harboring the aneurysm and flow replacement intra-to-intracranial (IC-IC) bypass via reimplantation of the right remaining PericA on the contralateral PericA (end-to-side anastomosis) was performed (in situ bypass). TICA of the dACA are exceptionally rare. Mechanical vessel wall injury and aneurysm formation of the dACA in blunt head trauma is very likely due to the proximity of the dACA with the rigid free edge of the falx. Given their nature as dissecting (complex) aneurysm, trapping and revascularization is a very important strategy. The interhemispheric cistern offers multiple revascularization options with its numerous donor vessels. The IC-IC bypass is often the simplest revascularization construct.

Key Words: Aneurysm—Traumatic aneurysm—TICA—Distal anterior cerebral artery—Pericallosal artery—Revascularization—Bypass surgery

Abbreviations: AFA, anteromedial frontal artery; CMA, callosomarginal artery; CT, computed tomography; CTA, computed tomography angiography; dACA, distal anterior cerebral artery; dMCA, distal middle cerebral artery; DSA, Digital subtracted angiography; EC- IC, extra-to-intracranial; IC-IC, intra-to-intracranial; ICA, internal carotid artery; IF, interhemispheric fissure; IFA, interomedial frontal artery; IMAX, internal maxillary artery; FPA, frontopolar artery; l, left; PA, paracentral artery; PCA, posterior cerebral artery; PericA, pericallosal artery; PFA, posteriomedial frontal artery; r, right; STA, superficial temporal artery; TICA, Traumatic intracranial aneurysm; MRA, magnetic resonance angiography; MRI, magnetic resonance imaging; FLAIR, fluid-attenuated inversion recovery; OFA, orbitofrontal artery; TOF, time of flight angiography; ICGVA, indocyanine green videoangiography

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Introduction

Traumatic intracranial aneurysms (TICA) have an overall incidence of less than 1% of all intracranial aneurysms and represent an exceptionally rare complication after head trauma.[1,2] TICA typically involve the anterior circulation vessels, with the most commonly described location being the supraclinoid internal carotid artery (ICA), the distal anterior cerebral artery (dACA) and the distal middle cerebral artery (dMCA), in descending order of incidence.[3,4]

In blunt head trauma the formation of TICA remains unclear. Several mechanisms, such as acceleration-deceleration and shifting vs. rigid structures, such as the sphenoid ridge, the falx or the tentorium have been discussed in case reports, but remain unclear.[3,5]

The risk of TICA rupture is especially high and the mortality rate has been described up to 50%.[3] TICA have the potential to evolve within time and thus hemorrhage may appear frequently after a delay of several weeks.[3,6] To achieve complete occlusion, TICA display a therapeutic challenge with their nature as complex aneurysms requiring difficult treatment strategies, i.e. deconstructive methods combined with revascularization strategies are often mandatory.[7–9] Direct reconstructive strategies by interventional neuroradiology (i.e. coils, stents) and microsurgery (clipping) are only rarely applicable when parent vessel preservation is mandatory.[4]

TICA of the dACA harbor special conditions with on the one hand often involvement of a bifurcation impeding revascularization strategies, and on the other hand with their location in the interhemispheric cistern with multiple donor vessels (left and right PericA and CMA, and also cortical vessels on the surface (EC-IC)).

In this article, we describe two cases of TICA of the dACA in young adults and discuss different aspects in the management of these patients: indications, revascularization strategies, and results are demonstrated.

Operative technique

Illustrative cases

CASE 1

History and examination

20-year-old patient who suffered severe blunt traumatic brain injury in a traffic accident. On arrival of the ambulance the patient presented with GCS 6 which lead to immediate intubation of the patient. The emergency computed tomography scan (CT) showed bifrontal contusion with extensive cerebral edema and subarachnoid hemorrhage predominantly in the anterior interhemispheric cistern. An intracranial pressure probe was inserted which showed an initial pressure of 50 mmHg. The patient was transferred to the intensive care unit and conservative intracranial pressure therapy was performed. The further course was favorable with good control of the intracranial cerebral pressure, and the patient was able to be extubated after 2 weeks. Complementary computed tomography angiography (CTA), which was performed to rule out an aneurysm as the cause of the subarachnoid hemorrhage, displayed an aneurysm of the right dACA (Fig. 1 A,B). The patient was therefore transferred to a tertiary center for the treatment of the aneurysm 4 weeks after the accident. Digital subtracted angiography (DSA) was performed and revealed a partially thrombosed 14 × 10 mm aneurysm of the rPericA, distal to the origin of the rCMA (Fig. 1 C,D). Due to the dissecting nature of the aneurysm it was not amenable to endovascular treatment. In an interdisciplinary discourse complete trapping of the rPericA aneurysm with revascularization of the territory of the rPericA via EC-IC bypass was decided.

Flow Replacement EC-IC Bypass via interposition of a radial artery graft

Revascularization of the territory of the rPericA was achieved via EC-IC bypass: the previously prepared radial artery graft was interposed between the stem of the superficial temporal artery (STA) and the cortical branch of the paracentral artery (A4 segment) at the convexity in a parasagittal location (Fig. 2). Complete trapping of the rPericA aneurysm was achieved through clip placement proximal and distal to the aneurysm.

Postoperative course

Postoperative magnetic resonance angiography (MRA) showed complete aneurysmal exclusion and a patent bypass (Fig. 2B).

In the postoperative course the patient presented with an epileptic seizure at day 3. A moderate anterograde amnesia was observed during neuropsychological examination with an otherwise normal neurological examination. The patient was discharged to home at day 8 after surgery.

CASE 2

History and examination

16-year-old patient with thunderclap headache and persistent severe headache after being hit by an Ice Hockey puck with high speed against his head. The accident occurred during the training of a professional ice hockey team where the patient was playing as a goalkeeper and wearing a helmet. The patient reports about thunderclap headache within seconds after the accident and the feeling of unconsciousness. However, unconsciousness was not observed by others. In the past, he had already experienced similar head trauma caused by the puck but had never experienced headache symptoms of this intensity. Neurological examination revealed no evidence of focal neurological deficits. Due to persistent headaches, MRI was performed after 2 weeks and displayed a polylobulated, partially thrombosed 16 × 10 mm aneurysm of the rPericA with hemosiderin deposit in the anterior interhemispheric fissure (Fig. 3 A,B). DSA confirmed this finding (Fig. 3 C-G). Neuroimaging showed three A2-segments: one A2-segment gave origin to the right orbitofrontal artery (rOFA) and continued into the rPericA harboring the aneurysm. Another A2-segment continued directly in the lPericA. These are the two segments which are visible through the injection of the right ICA in the DSA (Fig. 3C-G). The third A2-segment is visible in the DSA via injection of the lICA: this segment gives origin to the lOFA and to the lCMA artery.

Flow Replacement in situ IC-IC Bypass with an End-to-side micro-anastomosis

An interhemispheric approach with a predominant right-sided parasagittal craniotomy was performed. The left CMA and the PericA on both sides were displayed after opening of the pericallosal cistern. Surgery revealed a strong fibrous adhesion between the falx and the dACA at the aneurysm site. The aneurysm and the dACA were sharply

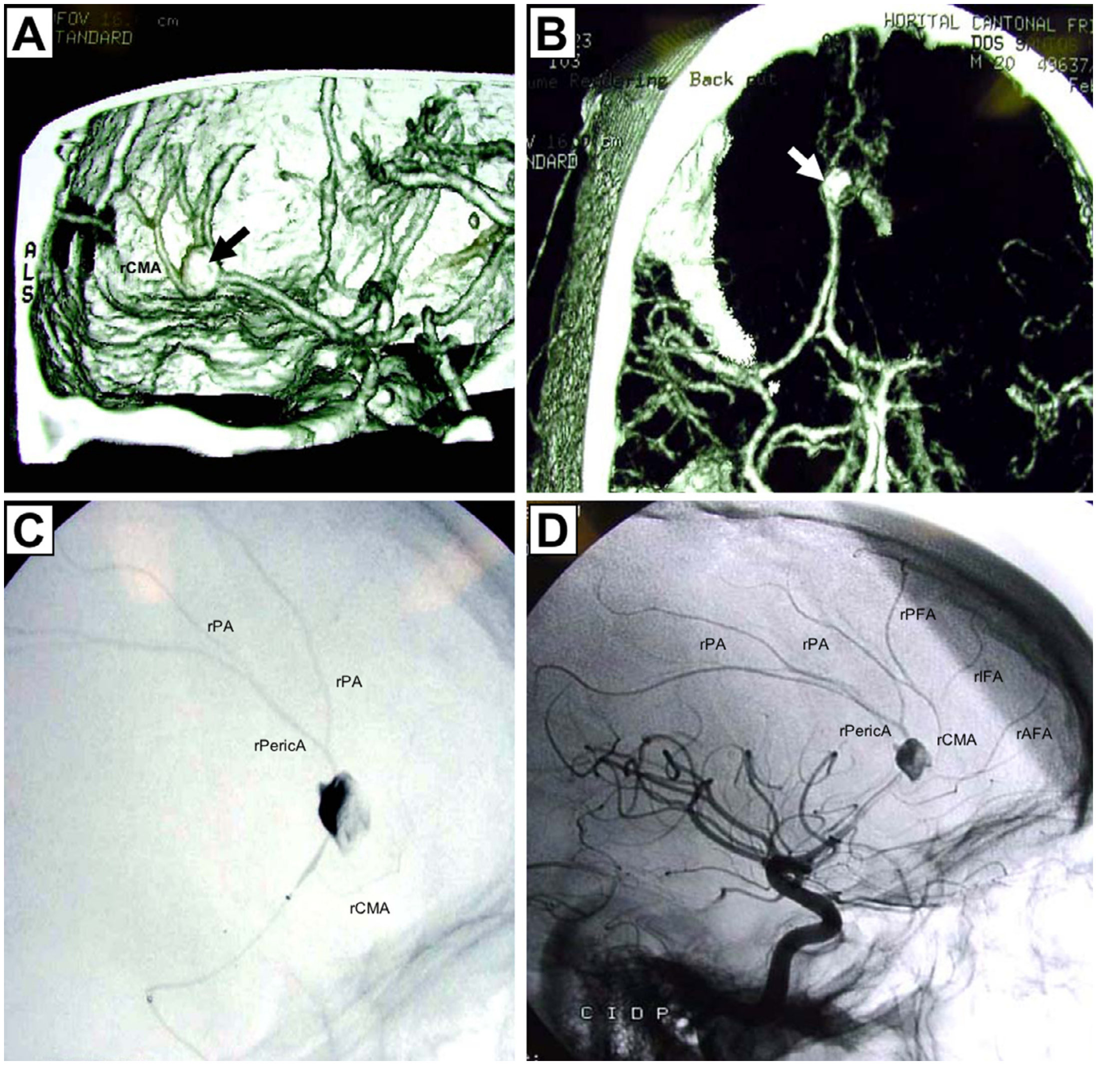

Figure 1. *Case 1: Sagittal (A) and axial section (B) of three-dimensional CT-Angio display an aneurysm (arrow) of the distal right anterior cerebral artery (dACA), distal to the origin of the right callosomarginal artery (CMA). Digital subtraction angiography (right internal carotid, lateral view) reveals a 14 × 10 mm partially thrombosed aneurysm of the right pericallosal artery (rPericA) (C, D). AFA = anteromedial frontal artery; CMA = callosomarginal artery; CT = computed tomography; IFA = interomedial frontal artery; l=left; PA = paracentral artery; PericA, pericallosal artery; PFA = posteriomedial frontal artery; r = right.*

dissected and freed from the dural adhesions. The distal A2 and proximal A3 segments on both sides were exposed to have a complete view of the angioanatomy. Temporary clipping of the rPericA was performed and the part of the vessel carrying the aneurysm was cut out. An end-to-end bypass of the two ends of the rPericA was not achievable due to the long distance in between - too much tension on the planned anastomosis had to be avoided. Thus, the right distal PericA stump was reimplanted into the lPericA via end-to-side micro-anastomosis (Fig. 4). Indocyanine Green videoangiography (ICGVA) showed patency of the anastomosis and the correctness of the flow direction. Intra-operative quantitative flow measurements (Charbel Micro-Flowprobe, Transonic Systems, Inc, Ithaca, NY) of the right and left PericA (distal to the micro-anastomosis) showed match of the flow before and after treatment. Neuromonitoring remained unchanged intraoperatively.

Postoperative course

The postoperative MRA showed no presence of any aneurysmal lesion and a patent in situ bypass (Fig. 4 D,E). The postoperative course was uneventful and the patient was discharged to home at day 4 without any neurological deficits.

Discussion

Several mechanisms have been proposed to explain the formation of TICA. The results of brain shifting or forceful stretching of the vessel by an adjacent structure, such as the sphenoid ridge, the falx or the tentorium have been discussed in the formation of TICA in blunt head trauma.[3] Whereas the mechanism of TICA formation of the dACA by direct injury of the arterial wall from penetrating

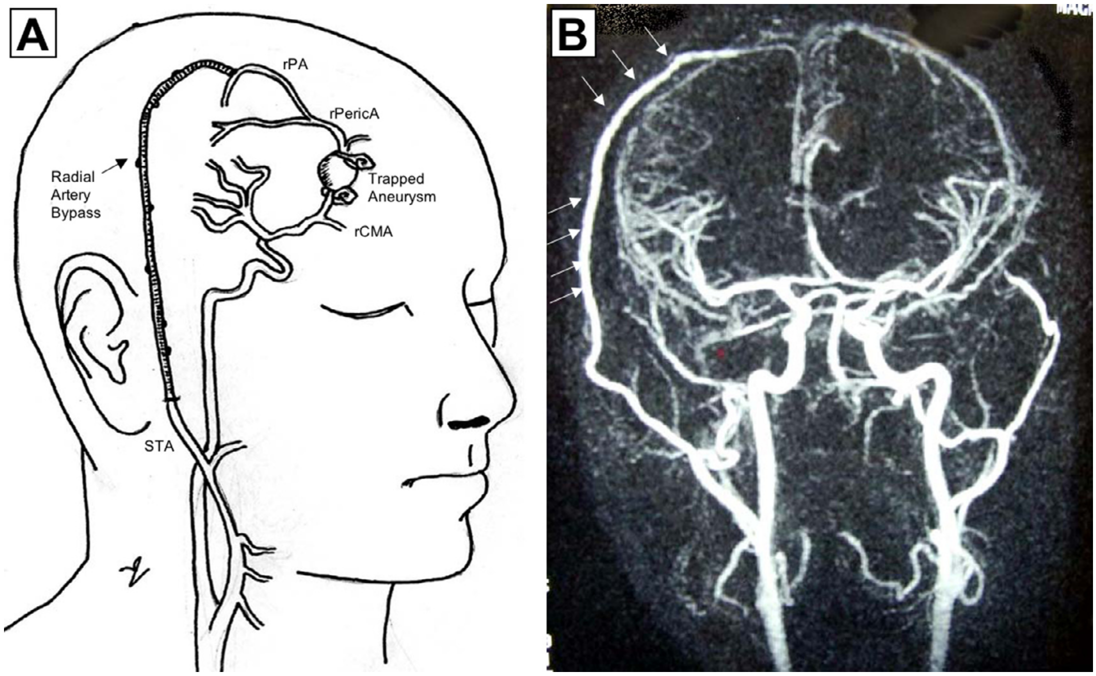

Figure 2. *Case 1: Diagrammatic drawing showing the operative strategy: To achieve complete trapping of the dissecting PericA aneurysm, clip placement proximal and distal to the aneurysm is performed with rPericA sacrifice, and revascularization of the territory of the rPericA is achieved by an EC-IC bypass with radial artery graft interposition (A). Postoperative coronal MR-angiographic (MRA) (B) shows complete trapping of the aneurysm and a large-caliber radial artery graft (arrows) extending from the temporal superficial artery and anastomosed to the paracentral artery (A4 segment). CMA = callosomarginal artery; l=left; PA = paracentral artery; PericA = pericallosal artery; r = right.*

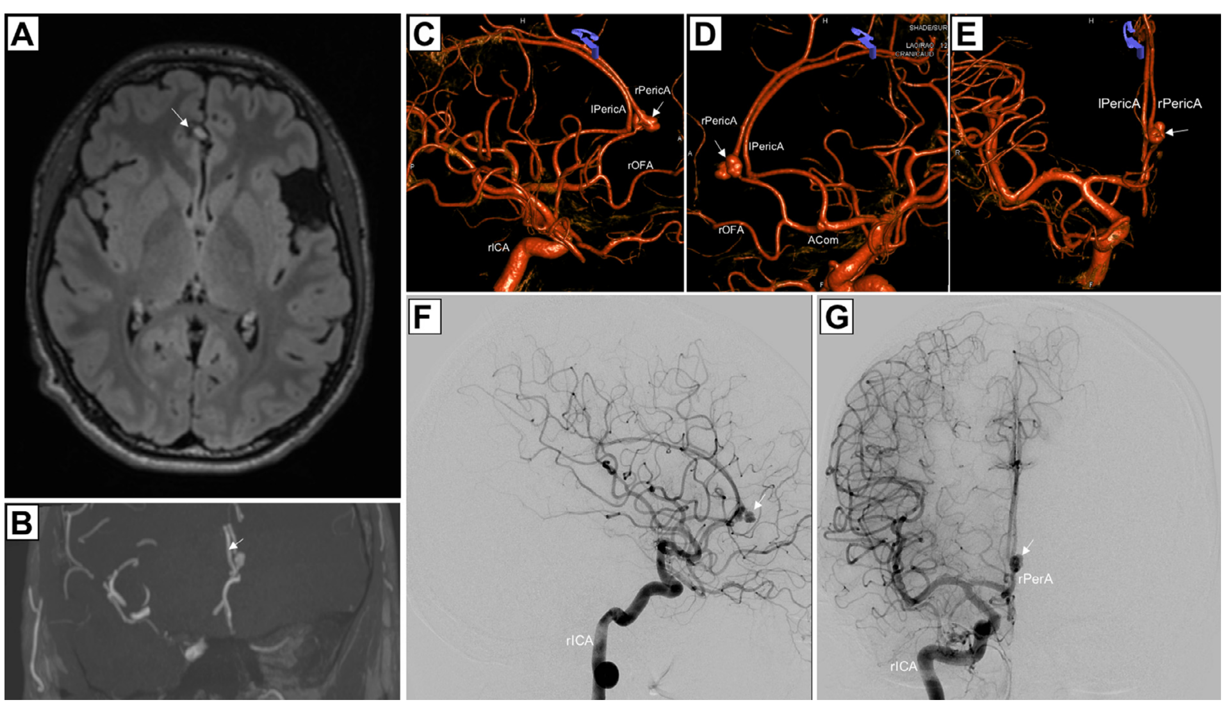

Figure 3. *Case 2: Axial FLAIR-weighted MRI shows a partially thrombosed aneurysm (arrow) with hemosiderin deposit in the anterior interhemispheric fissure (IF) (A). Coronar TOF section displays the polylobulated, partially thrombosed 16 × 10 mm aneurysm (arrow) of the right dACA (B). DSA shows a partially thrombosed polylobulated aneurysm of the rPericA (lateral (C,D) and anterior-posterior (E) views of color coded DSA after right carotid artery injection). There are two A2 segments visible through injection of the rICA (DSA): one A2-segment gives origin to the right orbitofrontal artery (rOFA) and continues into the rPericA harboring the aneurysm. Another A2-segment continues directly in the lPericA. Lateral (F) and anterior-posterior (G) view of non-color coded DSA. The partially thrombosed polylobulated aneurysm of the rPericA is marked with an arrow. CMA = callosomarginal artery; dACA = distal anterior cerebral artery, ICA = internal carotid artery; OFA= orbitofrontal artery; l=left; PericA = pericallosal artery; r = right.*

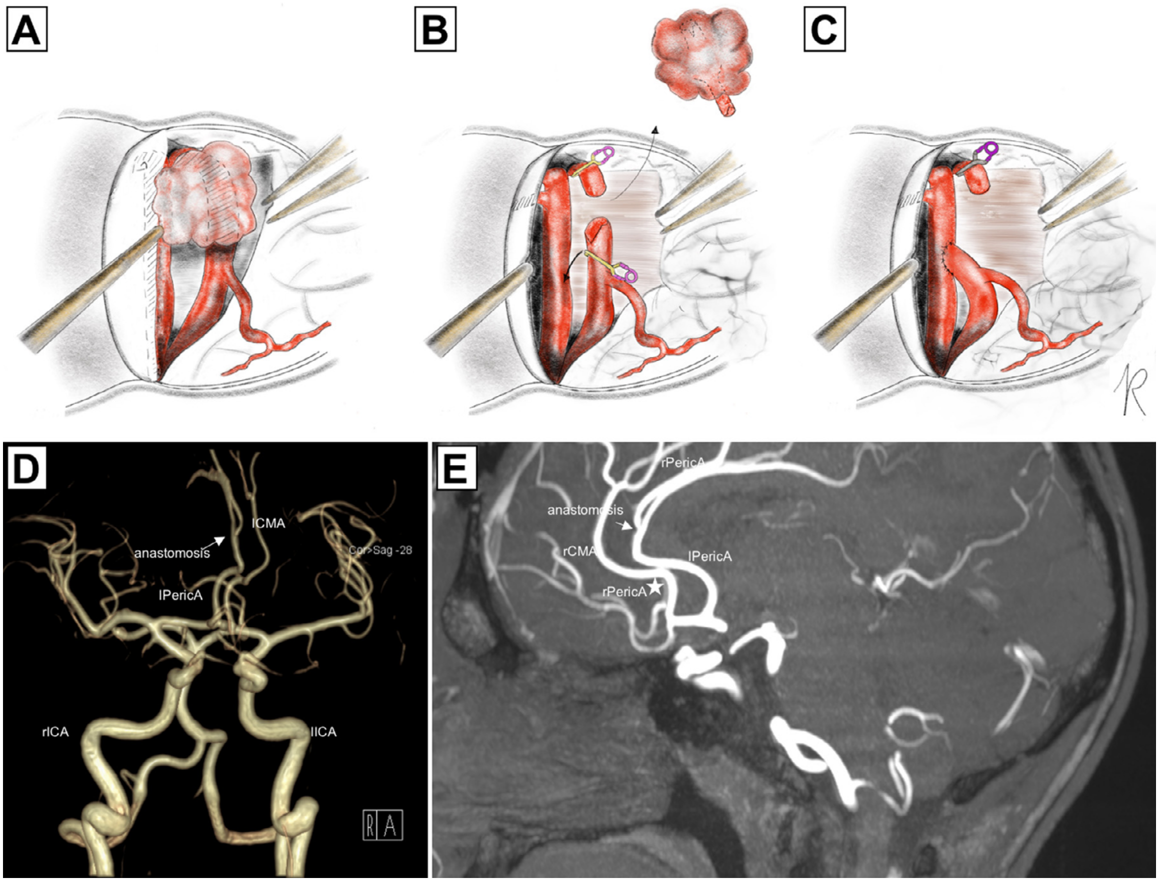

Figure 4. *Case 2: Diagrammatic drawing (A-C) showing the operative strategy: To achieve complete trapping of the dissecting PericA aneurysm, microsurgical excision of the A3- segment harboring the aneurysm and flow replacement intra-to-intracranial (IC-IC) bypass via reimplantation of the right remaining PericA on the contralateral PericA (end-to-side anastomosis) is performed. (A). Postoperative contrast-enhanced MRA (D) and TOF (E) verifies the patency of the end-to-side anastomosis between the distal vessel of the right remaining PerA and the native lPerA (end-to-side anastomosis marked with an arrow); the donor site is marked by a star. CMA = callosomarginal artery; ICA = internal carotid artery; l=left; PericA = pericallosal artery; r = right.*

wounds caused by bone fragments or a variety of missiles or weapons is unquestioned, the mechanism in blunt head trauma needs still to be answered, however the proximity between the falx and the dACA is most likely an anatomic explanation and was first described by Scholtes et al.[10−14]

Here we present two cases of TICA of the rPericA in young adults with previously blunt head trauma. In Case 1 the dissecting aneurysms of the PericA were in close proximity to the junction of the CMA. Another conceivable mechanism in our opinion is that during blunt head trauma, the rigid free edge of the falx leads to fixation of the PericA, whereas brain shifting, due the accelerating-decelerating forces, leads to a shift of the ipsilateral CMA in the opposite direction of the PericA. The transmission of significant shear forces on the joint bifurcation of the PericA and CMA could induce consecutive formation of a dissecting aneurysm.

Regardless of the precise mechanism of formation of TICA of the dACA, these aneurysms have to be considered as complex aneurysms due to their dissection origin with inherent therapeutic challenges.[15−17] The combination of trapping with a revascularization procedure is often the safest strategy.

The herein reported dACA aneurysms were in fact not amenable to endovascular treatment or selective clip exclusion and complete trapping of the aneurysms had to be performed, associated to flow-replacement bypass strategies. In Case 1 flow replacement EC-IC Bypass was performed by interposing a radial artery graft between the STA trunk and a superficial A4-recipient. The bypass was performed before the aneurysm exclusion. In Case 2 Flow Replacement in Situ IC-IC Bypass was executed via reimplantation of the right remaining PericA on the contralateral PericA (end-to-side anastomosis). The bypass was performed after aneurysm exclusion.

For dACA anerurysms, one can contemplate the use of either EC-IC or IC-IC bypass. Concerning EC-IC revascularization strategies, the first to be mentioned is the STA-ACA bypass. The STA is however rarely long enough to reach the parasagittal area or the interhemispheric fissure (IF).[18] Therefore EC-IC bypass strategies must often consider the use of an interposition graft. Due to caliber of the recipient vessel (A3 or A4), an arterial graft is preferred.

As donor artery one could choose the STA trunk (as reported in case 1) or the internal maxillary artery (IMAX).[19] Rarely one could consider the use of the external carotid artery (ECA) - in this case one must be sure the arterial graft is long enough to reach the IF. As recipient one could consider the use of a parasagittal A4-segment, as well as a more proximal A3-vessel in the IF and pericallosal cistern. It is however mandatory that the recipient represents a distal segment of the artery whose sacrifice is necessary to treat the aneurysm. ICGVA is helpful to confirm correctness of the recipient, mostly if it lies superficially.[16,20–24] EC-IC have the advantage that a superficial (A4-parasagittal) recipient can be chosen, thus avoiding working in the depth of the IF. Another advantage is that revascularization can be performed before aneurysmal trapping, thus avoiding the risk of cerebral ischemia. Furthermore, in case of anastomosis occlusion the patient will experience only unilateral ischemic problems, given that EC-IC bypass is "unilateral revascularization surgery". As disadvantage, EC-IC bypass for dACA aneurysms are more complex procedures, which need longer incision including STA-preparation, harvesting of the graft and two microanastomoses, with subsequent longer operative time.

Concerning IC-IC revascularization strategies, the angioanatomical characteristics of the interhemispheric fissure and of the pericallosal cistern offer a great variety of A3-donor and recipients, i.e. left and right PericA and CMA arteries. Two applicable IC-IC bypass strategies are: 1) revascularization of the sacrificed branch via reimplantation on a branch originating from the contralateral A2 via end-to-side anastomosis ("after" aneurysmal trapping or excision) − as performed in case 2; 2) revascularization of the sacrificed branch via side-to-side anastomosis (in the pericallosal cistern) with a branch originating from the contralateral A2 ("before" aneurysm trapping). This second IC-IC strategy has the advantage that the bypass can be performed before aneurysmal trapping, with less risk of cerebral ischemia. However, the execution of a side-to-side micro-anastomosis in the depth is more demanding. Furthermore, the failure of a side-to-side microanastomosis threatens the permeability of both the donor and the recipient vessel.

These IC-IC bypass procedures are less complex: in fact, only a small bicoronal incision is needed, no harvesting of the graft is necessary, and only one anastomosis needs to be performed. Operation time is therefore shorter compared to EC-IC strategies. As disadvantage, performing a microanastomosis in a deeper and narrower space such as the interhemispheric fissure is technically clearly more demanding requiring experienced cerebrovascular surgeons. In addition, IC-IC bypass procedures are "bilateral revascularization" surgeries. Thus, in case of anastomosis occlusion, the patients will (most probably) suffer from bilateral ischemic symptoms.

In very rare instances, when the artery harboring the aneurysm is redundant, one could consider excising the aneurysm and connecting the stumps via end-to-end micro-anastomosis. This strategy seems promising, while on the one hand provoking only unilateral risk of ischemia ("unilateral revascularization" surgery) and on the other hand the capacity to reconstruct the normal angioanatomy. However, because tension on a micro-anastomosis should be avoided, it rarely represents a safe option (in fact in case 2 we considered an end-to-end microanastomosis, but the gap was too long).

Our decision-making favors more and more the simplest procedure and construct which is often IC-IC Bypass. The privileged angioanatomy of the pericallosal cistern with its multiple donors and recipients allows the surgeon to customize the in situ (IC-IC) bypass to the aneurysmal lesion and therefore avoid more complex EC-IC procedures.

EC-IC bypass remains however a good and safe alternative. Treatment decision has to be tailored to the individual patient and his angioananatomical characteristics. The main objective is to obtain sufficient flow replacement with the safest revascularization option. Intra-operative tools in bypass surgery remain very important to confirm the bypass function, and ICGVA allows to verify patency of the anastomosis. Intra-operative quantitative flow measurement enables verification of pre- and post-anastomosis flow matching. This, together with intraoperative neuromonitoring (IONM), allows the surgeon to proof the efficiency of revascularization procedures and minimize the risk of ischemia.[23]

Conclusion

TICA of the dACA are exceptionally rare but very likely possible due to the proximity of the falx. Given their nature as dissecting (complex) aneurysm, trapping and revascularization are an efficient strategy. The interhemispheric fissure and pericallosal cistern offer multiple revascularization options with its numerous donor and recipient A3-vessels (pericallosal and callosomarginal arteries), which makes IC-IC bypass strategies feasible and often the simplest revascularization construct to be chosen.

Authors Contributions

JV, LR - conception and design, acquisition of data, analysis and interpretation of data; drafting the article

GE - analysis and interpretation of data, drafting the article, critically revising the article

Statement of ethics

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

The institutional review board approved the use of registry data for clinical research (KEK-ZH 2012−0244). Written informed consent was obtained from the patient for publication of this case report and any accompanying images.

Declaration of Competing Statement

None of the authors report a conflict of interest related to this case report.

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